

A Spectrum Analyser I

A spectrum analyser is an extremely useful piece of test equipment.

If you don't have one, why not read on, as Andrew Holme describes his home-built version.

Fig. 1: The block diagram of Andrew's design.

I decided to try my hand at building a spectrum analyser after seeing a design by Roger Blackwell G4PMK, in *The Radio Communication Handbook*. I had to adapt Roger's design though, because I couldn't get the Motorola MC 3356 i.c. used in his design. This article is an account of what I came up with, how it performed and how it might be improved.

A block diagram of the analyser is shown in Fig. 1. You'll see that it's, in effect, a dual conversion superhet with a video output rather than audio. The unit takes input signals in the range 0-50MHz, mixing them with the output from the first oscillator, a voltage controlled oscillator (v.c.o.). So, up-converting the band to a first intermediate frequency (i.f.) of 170MHz.

Although I've not shown it in any of the diagrams, a low-pass filter is required at the input, otherwise there would be many more spurious signals, due to unwanted inputs. There have been several low-pass filter designs in PW that would be suitable.

Before filtering, the mixed signals from the first mixer are broadband amplified (20dB) before passing through the helical filter (centred on 170MHz). The first i.f. was chosen to suit a helical filter I had in stock. There's no real reason why another frequency (such as 145MHz) couldn't be used instead. The helical filter's bandwidth of 2MHz, serves only to reduce or remove spurious responses.

Spurious Output

Without the helical filter, there will be many spurious output signals at 26.45, 31.8, 38.833, 45.967 and 63.6MHz. These spurii are due to harmonics created from the first mixer, that fall exactly 10.7MHz above or below harmonics of the second local oscillator.

The narrower first i.f. band of signals, is then mixed again, this time with the output of a crystal oscillator (159.3MHz) to create the second i.f. This time a narrow band crystal filter with a centre frequency of 10.7MHz is used, and it's this crystal filter that determines the actual resolution bandwidth.

So, let us turn now to the main controlling sweep generator, the circuit of which, is shown in Fig. 2. This circuit consists of a '555' timer (IC1) that controls the sweep rate. Variable resistor Ra sets the speed, while an integration function circuit around IC2 generates the ramp voltages. Integrator capacitor Ca is a polyester layer type.

Other controls are: Rb, which sets the sweep width and Rd (coarse) and Rc (fine) variables, set the display centre frequency as coarse and fine 'tune'. I could have used a 10-turn pot to set the centre frequency, but frequency changes are faster to achieve with separate controls.

The sweep output on IC4 pin 6 is directly connected to the v.c.o. control input. The oscilloscope is triggered using the flyback pulses on IC1 pin 3. Most spectrum analyser circuits usually have the oscilloscope's X-input driven by a ramp voltage. But my 'scope doesn't have an X-input!

Sharp And Steady

Smoothing at the input to IC5 (pin 3) is essential for a sharp, steady display when zooming in. Ca, c and d are 270nF metallised polyester film capacitors. I put three capacitors in parallel as I had no bigger value non-polarised types to hand. Electrolytics are suitable for power supply decoupling, though a ceramic disc decouples pin 5 of IC1.

The 741 type i.c. is adequate in this application except for its limited output swing. A rail-to-rail output would be better. The 12V rail itself is also a limitation, as some varicap diodes need up to 30V. The POS-300 v.c.o. mentioned elsewhere requires only a 1-16V swing for the control voltage.

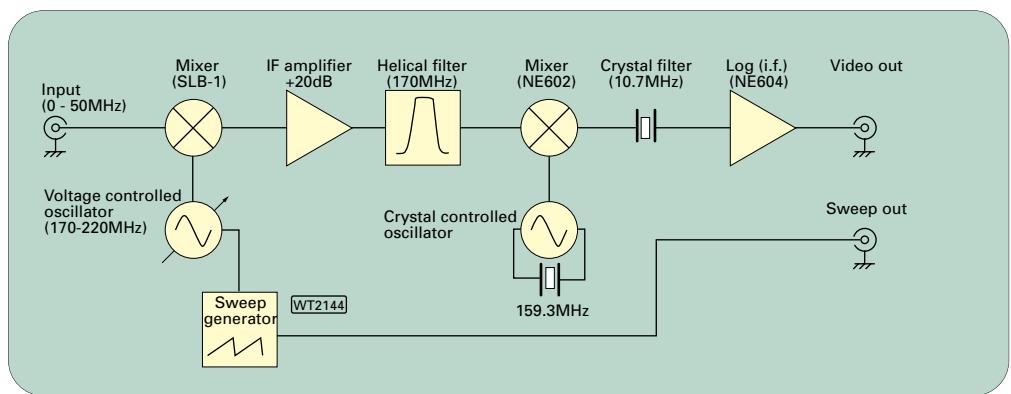
The front-end schematic is shown in Fig. 3 And is as outlined above. The inductor, RFC, in the supply feed of the IC6, is made of two turns of 0.45mm (26 s.w.g.) enamelled copper wire on a ferrite bead. The helical filter, a Toko 272MT-1007A, was purchased from Barend Hendrickson.

For this application, the i.f. and r.f. ports of the SBL-1 mixer are reversed. The analyser input (0-50MHz) is fed to pins 3/4 because these pins are directly coupled to the internal diode ring mixer, enabling very low input frequencies to be up-converted to the first i.f. stage. The transformer-coupled ports, of the SLB-1, don't work down to low frequencies.

Optimum Balance

For optimum balance, the SBL-1 requires a 50Ω broadband resistive termination on all ports. The 4dB attenuator at the output port was an attempt to provide this. A 2.5dB pad was used on the v.c.o. input. The SBL-1 requires +7dBm (1.4V peak to peak) drive from the local oscillator (l.o.). The output of my v.c.o. amplifier is +9.5dBm. The POS-300 output level is +10dBm so a 3dB pad would be required if that were used.

The MMIC, IC6 provides 20dB of gain to compensate for the SBL-1's insertion loss. The signal



In Your Shack!

suffers 6dB loss in the mixer, 4dB more in the attenuator and a further 9dB through the filter. So, I placed the gain before the filter to improve overall sensitivity.

Conveniently, the MMIC is powered through the filter. The R-BIAS resistor, sets the current at 45mA. Unfortunately, the MMIC doesn't see a broadband match. A better solution might be to place a further small attenuator after the i.c. or to use a diplexer.

Now to the second i.f. stage, shown in Fig. 4, which shows the second mixer, crystal filter and logarithmic amplifier, that make up the second i.f. stage. The NE600 series of i.c.s were originally developed for analogue cellular 'phones.

Now Obsolete

Although still popular with amateur constructors, regrettably, both i.c.s are now obsolete[‡]. The NE602 contains an r.f. amplifier, oscillator transistor and balanced mixer, while the NE604 is the complete electronics of an i.f. amplifier and f.m. demodulator. (*‡ Equivalents to the NE602, labelled SA602AN and SA612AN are now available from RS Components. Search <http://www.rswww.com> for SA602AN or SA612AN.*

Editor)

The inductor in the 170MHz tuned circuit, L2, is a Toko S18 series 0.040µH coil with ferrite slug. The filter coil, L3, consists of five turns of 0.45mm (26s.w.g.) enamelled copper wire on a ferrite bead. The 10.7MHz tuned circuit, T1, is a Toko KACSK3894A coil.

I adjusted the input matching circuit by connecting a terminated oscilloscope to the input whilst injecting a signal into L2 using an inductively coupled oscillator. The optimum oscillator drive level into pin 6 is 200mV peak-to-peak (-10dBm in R1).

The termination impedance (1.5kΩ) of the 10M15A crystal filter is compatible with the single-ended output impedance

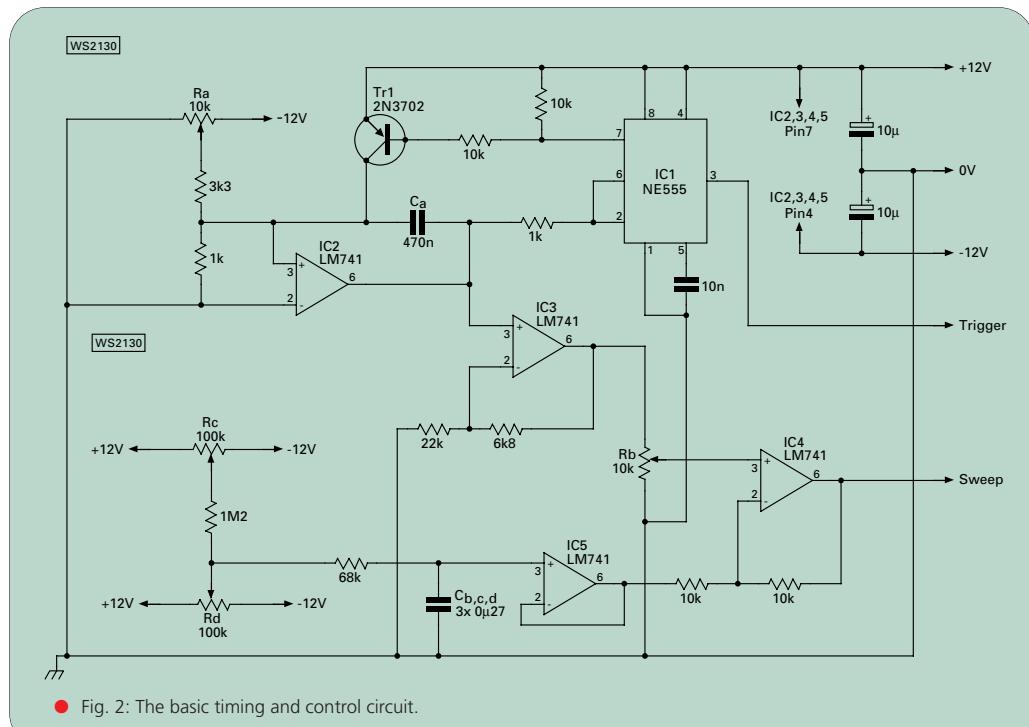


Fig. 2: The basic timing and control circuit.

of the NE602. Though the matching of the crystal filter to the NE604 via T1, and the purpose of resistors R2 and R3 require explanation.

The NE604 i.c. has over 100dB of gain. To ensure stability, the manufacturer's data sheet recommends the use of external shunt resistors. The 1.6kΩ input resistance at pin 1 is shunted by R2. The filter 'sees' 1.66kΩ across half the

primary of T1, which has a turns ratio of 7+7 to 4. The 82pF capacitor is integral to the Toko coil.

No attempt is made to match the 1kΩ output impedance of the first i.f. amplifier at pin 14 to the 330Ω termination impedance of the ceramic filter, however, the input impedance of the limiter at pin 12 in parallel with R3 correctly terminates the filter output.

Aids Stability

Resistor R3 also aids stability. A 12dB insertion loss is required between pins 12 and 14 for maximum received signal strength indication (r.s.s.i.) linearity. This was not achieved and so the unit is not completely linear.

Good power supply decoupling is essential with so much gain so, monolithic

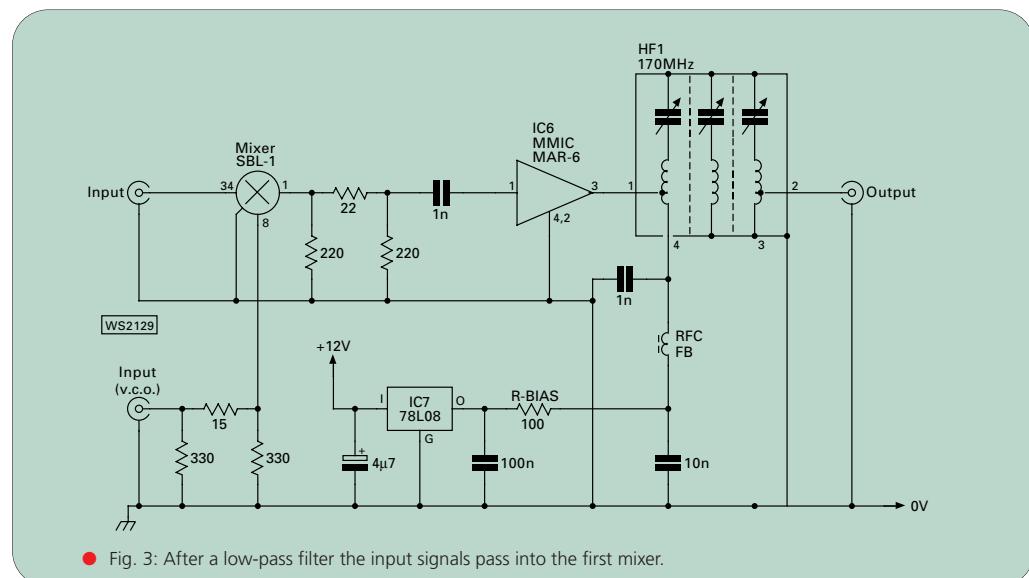


Fig. 3: After a low-pass filter the input signals pass into the first mixer.

- Fig. 4: The signal levels are detected in the second i.f. circuit shown here.

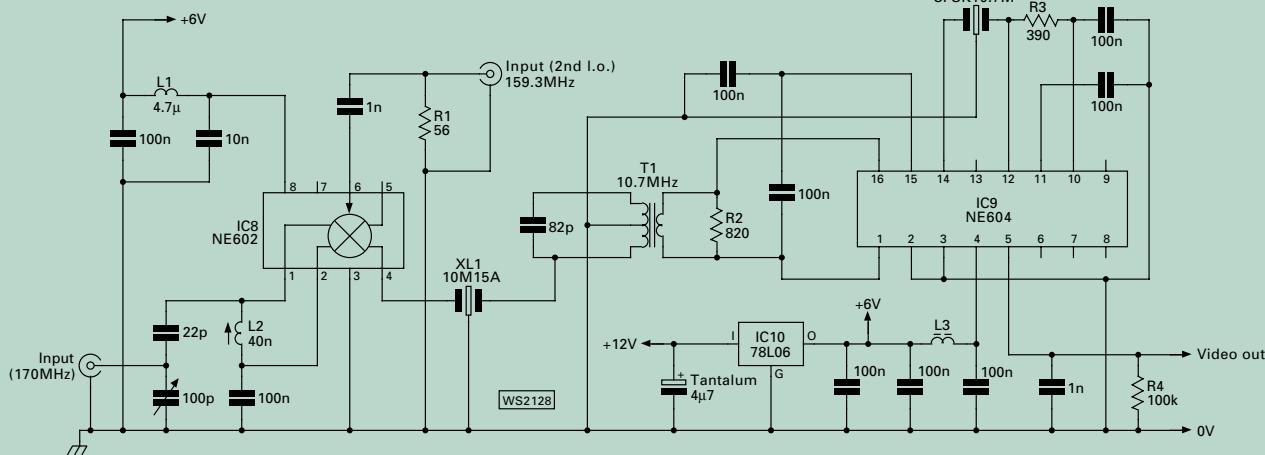


Fig. 5:
Looking down
on the
components
of the first
mixer p.c.b.

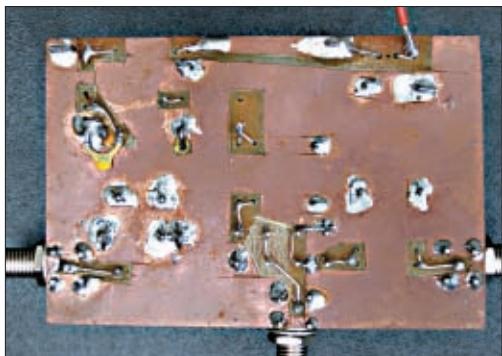


Fig. 6: The
first mixer
board from
below.



Fig. 7: The
second i.f.
board follows
the general
layout of its
circuit
diagram.

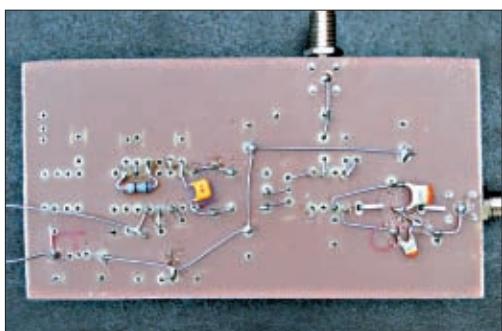


Fig. 8: The
second i.f.
and detector
board from
below.

ceramic decoupling capacitors were used throughout. An r.s.s.i. output greater than 250mV without an input signal is an indication of unwanted oscillation.

I was pleased to note that on my prototype, the quiescent r.s.s.i. was well below 200mV. Fortunately, a quadrature coil is not required in this application, as the audio output is not used. This probably helps to reduce feedback.

My original voltage controlled oscillator (v.c.o.) is a varicap-controlled f.e.t. oscillator, followed by an emitter-follower stage, made up from discrete components. An amplifier stage, to raise the output sufficient for the SLB-1 mixer, consists of a pair of cascaded MSA-0404 MMICs.

Other than that description, I'm not going to describe the first oscillator in any more detail, because I recommend using a commercial v.c.o. such as the Mini-Circuits POS-300 instead. This module can be

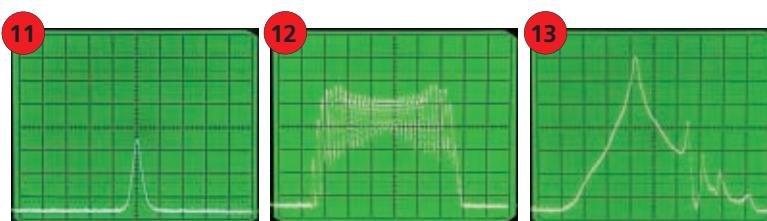
mounted adjacent to the first mixer. Its compactness, frequency span and linearity are unbeatable!

Similarly, I won't describe the second local oscillator either, except to say it was a separate Butler circuit using a custom made fifth-overtone 159.3MHz crystal. Though for my next version, I'll probably use the NE602/612's internal oscillator which, according to a Philips application note, operates reliably with crystals 'cut' as high as the seventh overtone.

The internal mixer of the NE602 isn't though, the best in the world at 170MHz! It's noisy and, the input match is tricky from a 50Ω input. But the circuit's saving grace is that it's a simple design to implement.

Construction

Throughout the construction, it's a good idea to use ground plane techniques for all r.f. circuitry. And my design was no different. The front-end Figs. 5



- Fig. 11: An un-modulated -85dBm carrier at 50kHz per division.
- Fig. 12: An f.m. signal with a deviation of 50kHz modulated by a 1kHz sine wave.
- Fig. 13: The analyser shows the response of its 2-pole 10M15A filter at approximately 50kHz per division.
- Fig. 14: The narrower, steeper sided passband of the 8-pole 10F15D at 20kHz per division.
- Fig. 15: A comb of 'pip' markers produced by a 1MHz square-wave crystal oscillator.
- Fig. 16: Signals down to 1µV e.m.f (-113dBm) are visible above the noise 'lawn' (4MHz per division).

and 6, was built on double-sided copper clad printed circuit board, though single sided board was used for the other r.f modules.

The front-end circuit itself was built on double-sided copper clad board. The MAR-6 amplifier was surface mounted by burring out a shallow recess with a sanding bit. Underneath, unwanted copper was removed by peeling it up whilst simultaneously applying heat.

I also used SMA connectors and miniature coaxial cable to route signals between the separate boards. The second i.f. board is shown in Figs. 7 and 8, which like the first mixer follows the circuit diagram in layout. The i.f. strip was built on single sided copper clad board with the copper acting as a ground plane. A few components, including R3, are mounted underneath the board.

I built a second i.f. strip to try out the 10F15D 8-pole filter. To match this filter's 3kΩ-termination impedance, a 1.5kΩ resistor was inserted in series with the filter input, and the value of R2 was increased to 2.7kΩ.

The sweep generator Figs. 9 and 10 was built on 0.1in perforated board using Molex connectors for external connections. The circuitry around IC1 and IC2 is 'borrowed' from Roger Blackwell's design.

Drilling Templates

I made drilling templates, marked out on 0.1in graph paper first. I could have created them on a computer, but often

'one-offs' are quicker by hand. I just pushed the legs of the helical filter through the paper to mark its pinout.

The boards were drilled with a small craft drill. The residual copper from around the holes, was cleared using a Vero cutting tool. Heat breaks in the copper foil were scored with a scalpel to make soldering to the top easier.

The prototype was constructed as six modules:

- 1 Sweep generator
- 2 Voltage controlled oscillator (v.c.o.)
- 3 An amplifier for the v.c.o.
- 4 Front-end (first mixer, i.f. amplifier and filter)
- 5 Second local oscillator
- 6 Second mixer and logarithmic i.f. amplifier / detector

You may wonder why I created so many modules. Well, my answer to that, is that the design was experimental. I didn't know how much gain would be needed to raise the output of the first oscillator to the required level until I'd built and tested it.

I also didn't want to put too much of the circuitry on one board in case something went wrong! This way, each module could be tested separately. As it was experimental, I also built two versions of the second i.f. to try different crystal filters.

Fun To Play

The spectrum analyser is fun to play with! Activity in the h.f. spectrum can be seen using a short antenna. I've also connected the analyser to the panoramic output of a Racal RA1217 Receiver. It's sometimes possible to

simultaneously see and hear individual c.w. signals.

Without an antenna, I can see the base and handset carriers of my cordless telephone at 31 and 40MHz and I can also see my neighbour's wireless baby alarm at 49MHz!

An un-modulated -85dBm carrier is shown in Fig. 11, at 50kHz per division using the 2-pole filter. The display is very stable. The screen of Fig. 12 shows an f.m. signal with a deviation of 50kHz modulated by a 1kHz sine wave. Varying the deviation, modulating frequency and sweep rate produces interesting effects!

The analyser can curve trace its own crystal filter, as Fig. 13 shows the response of the 2-pole 10M15A at approximately 50kHz per division. The second peak is 34dB below the top.

The well defined curve of Fig. 14 is the narrower, steeper sided pass-band of the 8-pole 10F15D at 20kHz per division. Passband ripple is visible. The character of these filters is not ideal for a spectrum analyser! They were designed for f.m. communications.

A comb of 'pip' markers produced by a 1MHz square-wave crystal oscillator is shown in Fig. 15. The span was 0.5 to 13.5MHz. Note the level of the first few even harmonics relative to the other peaks. A perfect square wave is composed of only odd harmonics.

The trace of Fig. 16 shows a -10dBm signal at 4MHz per division. Signals down to 1μV

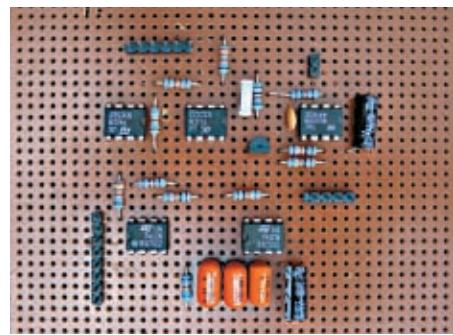


Fig. 9: A perf-board layout for the control and sweep oscillator.

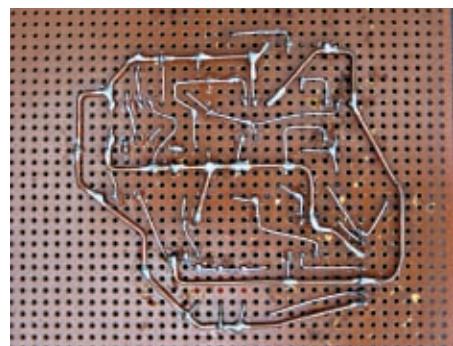
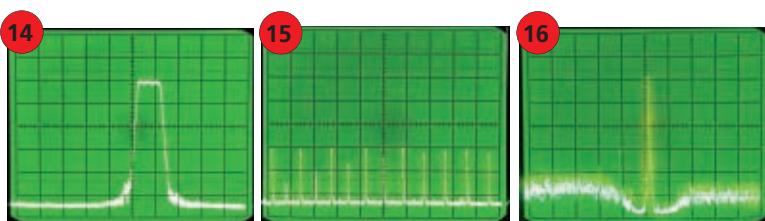


Fig. 10: Interconnections on the control oscillator board.

e.m.f (-113dBm) are visible above the noise lawn. The r.s.s.i. is fairly logarithmic up to -30dBm where it limits, giving a dynamic range of about 80dB. Inputs above -20dBm increase the noise level across the band - except near the carrier. I suspect the MAR-6 output only sees a 50Ω load in this quiet zone.

Although both, the NE602 and the NE604 i.c.s have been discontinued, samples can still be obtained. I found Barend Hendriksen in Holland a useful source for r.f. components.

I can also recommend another source at **Sycom** where **Robin G3NFV** will often look specifically for many components for PW and similar projects. The SMA plugs and sockets, along with other 'professional' parts, can often be picked up cheaply at rallies and 'junk sales'. **PW**



References

Barend Hendriksen
<http://www.xs4all.nl/~barendh>

Sycom: Tel: 01372 372587

Philips application note AN1983 *Crystal oscillators and frequency multipliers using the NE602 and NE612* (available in PDF format; search the Internet for AN1983)

Wes Hayward W7ZOI, and Terry White K7TAU, A Spectrum Analyzer for the Radio Amateur *QST*, August and September of 1998

Roger Blackwell, Simple Spectrum Analyser *Radio Communication Handbook*, 6th Edition, RSGB.

There are many interesting articles about spectrum analysers on the Internet. Some to try are:

<http://www.nitehawk.com/rasmit/sa50.html>

<http://www.qsl.net/n9zia/wireless/pdf/9808035.pdf>

<http://www.qsl.net/n9zia/wireless/pdf/9809037.pdf>

<http://www.bright.net/~kanga/w7zoi/SAPhotos.html>

http://www06.u-page.so-net.ne.jp/ga2/semra/speana/e_speana.htm